after birth. He has dissected and figured eight or nine of the more important stages, and shown the relative alteration of each part consecutively, commencing with the *Zœa* taken from the egg, and pursued the observations through the older forms to that of the adult *Carcinus*.

The paper is carefully illustrated by drawings made by the author.

XIX. "On the Electro-dynamic Qualities of Metals:—Effects of Magnetization on the Electric Conductivity of Nickel and of Iron." By Professor W. THOMSON, F.R.S. Received June 18, 1857.

I have already communicated to the Royal Society a description of experiments by which I found that iron, when subjected to magnetic force, acquires an increase of resistance to the conduction of electricity along, and a diminution of resistance to the conduction of electricity across, the lines of magnetization*. By experiments more recently made, I have ascertained that the electric conductivity of nickel is similarly influenced by magnetism, but to a greater degree, and with a curious difference from iron in the relative magnitudes of the transverse and longitudinal effects.

In these experiments the effect of transverse magnetization was first tested on a little rectangular piece of nickel 1·2 inch long, ·52 of an inch broad, and ·12 thick, being the "keeper" of the nickel horse-shoe (§ 143) belonging to the Industrial Museum of Edinburgh, and put at my disposal for experimental purposes through the kindness of Dr. George Wilson. Exactly the method described in § 175 of my previous communication referred to above, was followed, and the result, readily found on the first trial, was as stated.

The effect of longitudinal magnetization on nickel was first found with some difficulty, by an arrangement with the horse-shoe itself, and magnetizing helix (§ 143), the former furnished with suitable electrodes for a powerful current through itself, and the system treated in all respects (including cooling by streams of cold water) as described in § 156, for a correspondiug experiment on iron. The

* See Phil. Trans. Bakerian Lecture, "On the Electro-dynamic Qualities of Metals," Feb. 27, 1856, § 146 of Part 4 and Part 5. In the present communication that paper will be referred to simply by the sectional (§) numbers.

result, determined by but a very slight indication, was, as stated above, that longitudinal magnetization augmented the resistance.

The magnetization of the small piece of metal between the poles of the Ruhmkorff electro-magnet being obviously much more intense than that of the larger piece under the influence merely of the smaller helix, I recurred to the plan of experiment (§ 175) by which the effect of transverse magnetization on the little rectangular piece of nickel was first tested, and I had an equal and similar piece of iron, and another of brass, all prepared to be tested, as well as the nickel, with either longitudinal or transverse magnetic force.

To each of the little rectangles of metal to be tested, a thin slip of copper (instead of lead, as in the experiment of § 175), of the same breadth (·52 of an inch), to serve as a reference conductor, was soldered longitudinally, and to the other end of the metal tested, a piece of copper to serve as an electrode, for the principal current, was soldered. The ends of a testing conductor, 6 feet of No. 18 copper wire, were soldered respectively to the last-mentioned end of the tested metal, and to a point in the reference-conductor found, so that the resistance between it and the junction of the reference-conductor with the tested conductor, should be about equal to the resistance in the latter.

A single element, consisting of four large double cells of Daniell's (§ 63), exposing in all 10 square feet of zinc surface to 17 square feet of copper, was used to send the testing current through the conducting system thus composed, by electrodes clamped to the ends of the principal conducting channel, just outside the points of attachment of the testing conductor.

The electro-magnet was excited by various battery arrangements, in different experiments, at best by 52 cells of Daniell's, each exposing 54 square inches of zinc surface to 90 square inches of copper, and arranged in a double battery* equivalent to one battery of 26 elements each of double surface. By accident, only a single battery of 26 elements was used in obtaining the numerical results stated below.

* This arrangement was found to give about the same strength of current through the coils of the electro-magnet, as a single battery of 52 of the same cells in series, and was therefore preferred as involving only half the amount of chemical action in each cell, and consequently maintaining its effect more constantly during many successive hours of use.

The nickel was first placed between the flat poles of the electro-magnet, with its length across the lines of force, and, one galvanometer electrode being kept soldered to the junction of the nickel and the copper reference-conductor, the other galvanometer electrode was applied to the testing conductor till the point (equipotential with that point of junction) which could be touched without giving any deflection of the needle, was found. A multiplying branch, 3 feet of No. 18 wire, was then soldered with its ends $\frac{3}{8}$ths of an inch on each side of this point, and, as soon as the solderings were cool, the corresponding point on this multiplying branch was found. The magnetizing current was after that sent in either direction through the coils of the electro-magnet, and it was found that the moveable galvanometer electrode had to be shifted over about $4\frac{1}{2}$ inches on the multiplying branch towards the end of the testing conductor connected with the nickel, that is to say, in such a direction as to indicate a *diminished resistance* in the nickel. When the same operations were gone through with the nickel placed longitudinally between the poles of the electro-magnet, the zero-point on the multiplying branch was shifted about 6 inches in the direction which indicated an *increased resistance* in the nickel.

The piece of iron similarly tested, gave effects in the same direction in each case, and the results originally obtained for iron (§§ 146, 155, 161–177) were thus verified.

No effect whatever could be discovered when the piece of brass was similarly tried. It is much to be desired that experiments with highly increased power, and with a better kind of galvanometer, should be made, to discover whatever very small influence is really produced by magnetic force on the comparatively non-magnetic metals.

The shifting of the neutral point on the multiplying branch required to balance the effect produced by the longitudinal magnetization in the iron, was only from $1\frac{1}{2}$ to 2 inches. Three inches were required to balance the opposite effect of the transverse magnetization.

Hence, with the same magnetic force, the effect of longitudinal magnetization in increasing the resistance, is from three to four times as great in nickel as in iron; but the contrary effect of transverse magnetization is nearly the same in the two metals with the same

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magnetic force. It may be remarked, in connexion with this comparison, that nickel was found by Faraday to lose its magnetic inductive capacity much more rapidly with elevation of temperature, and that it must consequently, as I have shown, experience a greater cooling effect with demagnetization* than iron, at the temperature of the metals in the experiment. It will be very important to test the new property for each metal at those higher temperatures at which it is very rapidly losing its magnetic property, and to test it at atmospheric temperature for cobalt, which, as Faraday discovered, actually gains magnetic inductive capacity as its temperature is raised from ordinary atmospheric temperatures, and which, consequently, must experience a heating effect with demagnetization and a cooling effect with magnetization.

The actual amount of the effects of magnetization on conductivity demonstrated by the experiments which have been described, may be estimated with some approach to accuracy from the preceding data. Thus the value of an inch on the multiplying branch would be the same as that of $\frac{1}{36} \times \frac{3}{4}$, or $\frac{1}{48}$ of an inch on the portion of the main testing conductor between its ends. The whole resistance of this $\frac{3}{4}$ of an inch of the main testing conductor, assisted by the attached multiplying branch of 36 inches, is of course less in the ratio of 48 to 49, than that of any simple $\frac{3}{4}$ of an inch of the testing conductor; but in the actual circumstances there will be no loss of accuracy in neglecting so small a difference. Hence the effect of the transverse magnetization of the nickel was to diminish its resistance in the ratio of half the length of the testing conductor diminished by $\frac{4\frac{1}{2}}{48}$ of an inch, to that of the same increased by the same, that is to say, in the ratio of $11\frac{31}{32}$ to $12\frac{1}{32}$, or of 383 to 385. Hence it appears that the resistance of the nickel, when under the transverse magnetizing force, was less by $\frac{1}{192}$, and similarly, that the resistance, when under the longitudinal magnetizing force, was greater by $\frac{1}{144}$, than when freed from magnetic influence; and that the effects of the transverse and of the longitudinal magnetizing forces on the iron were to diminish its resistance and to increase its resistance by $\frac{1}{288}$ and $\frac{1}{500}$ respectively. The first effect which I succeeded in estimating (§ 155) amounted to only $\frac{1}{3000}$, being the increase of resistance in an iron wire when longitudinally

* See Nichol's Cyclopædia of Physical Science, article 'Thermo-magnetism.'

magnetized by a not very powerfully excited helix surrounding it. In the recent experiments the magnetizing force was (we may infer) far greater.

It is to be remarked that the results now brought forward do not afford ground for a quantitative comparison between the effects of the same degree of magnetism, on the resistance to electric conduction along and across the lines of magnetization, in either one metal or the other, in consequence of the oblong form of the specimens used in the experiment. It is probable that in each metal, but especially in the nickel of which the specific inductive capacity is less than that of iron, the transverse magnetization was more intense than the longitudinal magnetization, since the poles of the electro-magnet were brought closer for the former than for the latter.

I hope before long to be able to make a strict comparison between the two effects for iron at least, if not for nickel also; and to find for each metal something of the law of variation of the conductivity with magnetizing forces of different strengths.

XX. "On the Electric Conductivity of Commercial Copper of various kinds." By Professor W. THOMSON, F.R.S. Received June 17, 1857.

In measuring the resistances of wires manufactured for submarine telegraphs, I was surprised to find differences between different specimens so great as most materially to affect their value in the electrical operations for which they are designed. It seemed at first that the process of twisting into wire-rope and covering with gutta-percha, to which some of the specimens had been subjected, must be looked to to find the explanation of these differences. After, however, a careful examination of copper-wire strands, some covered, some uncovered, some varnished with india-rubber, and some oxidized by ignition in a hot flame, it was ascertained that none of these circumstances produced any sensible influence on the whole resistance; and it was found that the wire-rope prepared for the Atlantic cable (No. 14 gauge, composed of seven No. 22 wires, and weighing altogether from 109 to 125 grains per foot) conducted about as well, on the average, as solid wire of the same mass: but, in the larger collection